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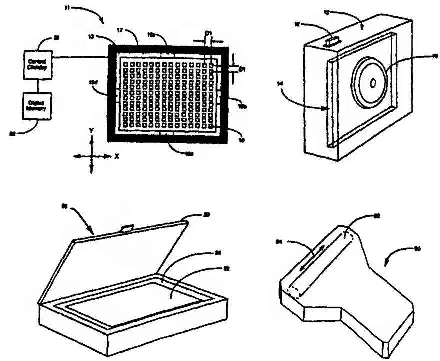

(57) Abstract

High-resolution digital imaging device, such as digital cameras and document scanners use a relatively low-resolution array (13) of photosensitive cells (19) wherein the array (13) has micro-motion mechanisms (15a, 15b, 15c and 15d) whereby the array (13) may be quickly moved incrementally to capture image information between the position of cells (19) on an unmoved array.

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Micro-Motion Mechanism to Improve Image Resolution of a Scan Array

By Inventor
Dan Kikinis

Field of the Invention

This invention is in the area of apparatus and methods for high-resolution scanning of images, and has particular application to scanning apparatus, digital cameras, and video-cameras.

Background of the Invention

The image capturing component of most image scanning devices such as digital cameras is an implementation of a specialized integrated circuit, called a charge-coupled device (CCD). A CCD comprises thousands of photosensitive semiconducting cells, each of which transforms light impinging on the individual cell into an electrical charge having a magnitude proportional to the intensity of the light. The light falling on an array of such cells arranged to capture an image is light reflected from a hard copy of a document to be scanned, or from objects and topography (In the case of a digital camera) viewed through a lens.

A single row of photosensitive semiconducting cells, typically referred to in the art as a linear CCD, sometimes called a scanning bar, often is used in scanning devices and high-resolution digital cameras. A camera (for example) equipped with a linear CCD captures an image as a series of narrow strips. In this technique the position of either the CCD or of the entity being scanned must be moved a number of times to complete a scan to record an image. The technique offers high resolution particularly in the direction at right angles to the row of CCD elements, depending on ability to adjust position of the entity to be scanned relative to the linear CCD. The technique, however, requires considerable time to capture an image, and is therefore not typically used for such as photography, where a scene may rapidly shift.

In contrast to a linear CCD, a two-dimensional CCD array allows

exposure of an entire two-dimensional grid of photosensitive semiconductor cells to an image, and a two-dimensional bit-map file may be quickly prepared by sensing the output of each of the cells in the array. This is the basis of a digital camera still camera and of a digital video camera, which records a series of frames, wherein each frame is a bit-map image.

A digital camera equipped with a two-dimensional CCD captures an image in a fraction of the time it takes a camera equipped with a linear CCD to capture an image. For this reason a digital camera equipped with a two-dimensional CCD, often termed a real-time digital camera in the art, may be used to photograph scenes that are stationary for only a short time, or even moving objects.

There is still a problem with a digital camera equipped with a two-dimensional CCD array, however. Such a camera, to produce the resolution available in one direction by use of a linear CCD and strip-by-strip exposures, would require a very large number of photosensitive semiconductor cells spaced very close together. Present ability to place such photosensitive elements in a two-dimensional array with high resolution is limited, and the cost of manufacturing such a planar array of CCDs is high.

Because of the difficulty of manufacturing and the concomitant cost, making real-time digital cameras affordable to many users requires unfortunate compromise in image resolution. That is to say, manufacturers install inexpensive, low-resolution CCDs in low-cost digital cameras.

What is clearly needed is a method to significantly increase the resolution of low-cost CCD bars and arrays without prohibitively increasing manufacturing cost.

Summary of the Invention

In a preferred embodiment of the present invention, a unique micro-motion mechanism is combined with a two-dimensional CCD array and suitable controls, allowing for rapid and highly accurate micro-displacement of a two-dimensional CCD in a scanning or

photographic procedure. By displacing a low-resolution, two-dimensional CCD array a small increment in the plane of the array after recording a scan, the increment being substantially less than the center distance between CCD elements, and making such displacements and recording new scans incrementally in both two-dimension directions, a very high-resolution composite image may be quickly recorded. This apparatus and method provides low-cost, high-resolution digital cameras.

In a preferred embodiment a system for capturing images is provided comprising an array of sensor cells including connection circuitry for coupling the cells to outside circuitry; and a micro-motion mechanism in contact with the array of sensor cells, including connections for power and control input to the micro-motion mechanism. The micro-motion mechanism is adapted for moving the cell array in at least one direction in the plane of the cell array.

In one embodiment the cell array comprises an array of charge-coupled devices (CCDs) implemented on a semiconductor substrate, but the invention is not limited by devices that sense visible light, and micro-motion mechanisms can take several forms, such as bi-metallic cantilevers and piezoelectric devices.

In alternative embodiments arrays can be linear arrays, such as a scanner bars, or CCD arrays in two dimensions, with sensor cells in columns and rows.

In combination with a suitable controller as a CPU and with digital memory and control routines, systems according to the invention can be adapted for various purposes, such a digital still camera, a digital video camera, and scanners of various sorts.

There are many advantages accruing for systems according to embodiments of the present invention. For example, CCD arrays for use with such as scanners, digital cameras, and video cameras can now be smaller and of lower physical resolution, with final resolution software controlled. Also, images with higher resolution than from conventional equipment may be made, many image filters and enhancements may rendered in software rather than hardware, making such systems inherently more versatile and flexible.

Brief Description of the Drawings

Fig. 1A is a plan view of a CCD system according an embodiment of the present invention, including a block diagram of control and storage circuitry.

Fig. 1B is an isometric view of a digital camera according to an embodiment of the present invention.

Fig. 1C is an isometric view of a flat-bed scanner according to an embodiment of the present invention.

Fig. 2 is a plan view of an enlarged portion of the CCD system of Fig. 1.

Fig. 3 is a diagram of a displacement sequence illustrating how two exemplary photosensitive semiconductor cells can be displaced in small discrete steps by a precisely controlled micro-motion mechanism according an embodiment of the present invention.

Fig. 4 is a diagram illustrating how a sequence of cell displacements according to an embodiment of the present invention may cause a photosensitive semiconductor cell dedicated to one color to exchange position with a photosensitive semiconductor cell of another color.

Fig. 5A is a plan view of a portion of the periphery of a CCD array with a bimetal micro-motion mechanism according an embodiment of the present invention.

Fig. 5B is an edge view of the bimetal micro-motion mechanism of Fig. 5A.

Fig. 6A is a plan view of the periphery of a CCD array showing a bimetal micro-motion mechanism having a current-control circuit according an alternative embodiment of the present invention.

Fig. 6B is an edge view of the bimetal micro-motion mechanism of Fig. 6A.

Fig. 7 is a plan view of a CCD array having a piezoelectric micro-motion mechanism according another embodiment of the present invention.

Fig. 8 is a plan view a three-color (RGB) camera mechanism according to another embodiment of the present invention, wherein each CCD is displaced independently by a micro-motion mechanism.

Fig. 9 is an isometric view of a video camera according to an embodiment of the present invention.

Fig. 10 is a generalized flow diagram depicting a sequence of logical steps in constructing an image according to an embodiment of the present invention.

Description of the Preferred Embodiments

General Description

Fig. 1A is a plan view of a system 11 according to an embodiment of the present invention comprising a CCD array 13 having a matrix of photosensitive semiconductor cells such as cell 19. The position of CCD array 13 within a frame 17 is precisely controlled by a set of micro-motion mechanisms 15a, 15b, 15c, 15d that bear against both frame 17 and CCD array 13.

There are a number of suitable micro-motion mechanisms known to the inventors for accomplishing physical displacement of array 134 relative to frame 17. In each case, the micro-motion mechanisms may be actuated by an electric current or charge.

Dimension D1 is the center distance in the exemplary case between CCDs in each direction X and Y. In Fig. 1A the center distance is the same in each direction, but this need not be so. Upon actuation, a set of micro-motion mechanisms displaces array 13 by a fraction of distance D1. Micro-motion mechanisms 15b and 15d in this example cause displacement in the X direction, and one extends while the other retracts. In other embodiments one controllable micro-motion mechanism (15b for example) may be used with the opposite element (15d in this case) being a resilient member. Similarly, micro-motion mechanisms 15a and 15c displace CCD array 13 in the Y direction.

System 11 includes suitable control circuitry 28 coupled to the cell array for powering the cell array and motion mechanisms, for sensing the output of individual cells, and for processing and storing in a digital memory 32 bit-mapped images based on sensed output of cells. Such circuitry is conventional and within the skill of persons with ordinary skill in the art.

By capturing the output of each of the cells of array 13 at the original position and again at positions wherein the array is moved incrementally in steps less than the center distance of cells in the array, and storing bit-map shading values relative to the outputs of the cells, one may produce a composite bit-mapped image having substantially greater resolution than the image possible from just one scan of the array. It is just necessary that the incremental movements be made quickly, and that there be suitable software in a computerized apparatus to combine and process the stored information to produce the higher resolution image.

Fig. 1B is an isometric view of a digital camera 12 according to an embodiment of the present invention and having a movable CCD system 14 as described above relative to Fig. 1A. Camera 12 focuses an image of outside entities and topography through a lens system 16 on internal CCD array 14 as in conventional digital cameras, but when the camera is triggered via switch 18 or similar trigger, multiple scans of the array are quickly executed and the results recorded, and an incremental movement of the CCD array is made in the plane of the array between each scan and recording. The result is several stored images which may be combined to produce a single image having higher resolution than any one of the single images.

Fig. 1C is an isometric view of a flat-bed scanner 20 having a movable CCD system 22 as described above relative to Fig. 1A. This scanner has top cover 26 and an upper glass surface 24 as is conventional. CCD array 22, however, is mounted with micro-motion mechanisms to be movable in increments in the plane of the array. A document is placed on glass 24, cover 26 is closed, and a scan sequence is triggered by a switch or other command to the scanner. Multiple scans are made of the CCD array with interspersed incremental movements between scans as described also above for the digital camera of Fig. 1B. The result is, as in the case of the digital camera, a series of bit mapped files that may be combined into a single file or image having substantially greater resolution than any one of the individual images taken in the sequence.

In practical scanner embodiments there may be lenses and focusing apparatus so an image of a document to be scanned may be

projected on a smaller CCD array as is done in a digital camera. In another alternative, a linear CCD bar may be incorporated and the scanner incorporates a document feed mechanism for feeding a document to be scanned past the liner CCD bar. In this embodiment, while the document is being fed, the linear CCD bar is moved laterally in small increments and multiple scans are made in the direction at right angles to the direction of document feeding as well as in the direction of document feeding. In this manner the resolution of an image of a scanned document may be increased, and a low-cost CCD may be used with fewer and more widely spaced cells than would otherwise be needed for a given resolution.

Fig. 1D is an isometric view of a hand-held scanner 60 according to yet another embodiment of the present invention. In this embodiment a linear CCD 62 is used, as is common for such scanners, and an image is acquired as the hand-held scanner is drawn across a document to be scanned. Output of cells is taken at increments of time during the movement of the scanner. Movement of the scanner substitutes for the motion imparted to a document by a document feeder in scanners that feed documents.

In the hand-held scanner of Fig. 1D, micro-motion mechanisms are incorporated to move the linear CCD in the direction of the linear axis, that is, in the direction of arrow 64 which is at right angles to the direction of movement of the scanner during a scan. Output of cells taken and stored now can be combined to produce an image having improved resolution in the direction of arrow 64.

Fig. 2 is a plan view of an enlarged portion of the CCD system of Fig. 1A showing a set of four photosensitive semiconductor cells 23, 25, 29, and 39, which may be any of the cells shown in Fig. 1. As described above, when micro-motion mechanisms 15a and 15c are actuated, all photosensitive semiconductor cells of CCD 13 move in the Y direction.

As an example of cell position adjustment, cell 25 may be moved by action of micro-motion mechanisms 15a and 15c to position 31, halfway between the former positions of cells 23 and 25. In the same operation cell 29 would move to position 30, and cells 23 and 39 would move to positions not shown in Fig. 2, but one-half of dimension D1 above the positions shown in Fig. 2.

If the output of the photosensitive cells of array 13 is recorded both before and after the movement induced by activating micro-motion mechanisms 15a and 15c and described above. the records can be used to produce two distinct images. or the records can be combined to form a single image with twice the Y-axis resolution of either of the two distinct images. The combination with higher resolution assumes the entity being scanned or photographed has not moved in the time required to move array 13 to the new position in the y-axis direction.

Similarly. micro-motion mechanisms 15b and 15d may be actuated to move array 13 in the x-direction with results similar to the results described above for movement in the y-direction. Cell 25 moves to a new position 33 one-half of dimension D1 in the x-direction. and halfway between the original positions of cells 25 and 29.

If the output of the photosensitive cells of array 13 is recorded both before and after the movement induced by activating micro-motion mechanisms 15b and 15d. the records can be used to produce two distinct images. or the records can be combined to form a single image with twice the X-axis resolution of either of the two distinct images. The combination with higher resolution assumes the entity being scanned or photographed has not moved in the time required to move array 13 to the new position in the X-axis direction. Taking advantage of the movement of one-half of the cell center distance in each of the X and Y-directions. and capturing the output of the cells at the original position and at each of the halfway points. provides three image arrays that may be combined to produce a single image with twice the two-dimensional resolution of any one of the single captured images.

In alternative embodiments of the present invention. precisely controlled micro-motion mechanisms may be activated to displace a CCD array in increments of a fraction of the cell center distance in the array. Fig. 3. for example. illustrates a displacement sequence that illustrates how two cells 43 and 45 can be displaced in small discrete steps by a precisely controlled micro-motion mechanism. In this example each cell traverses the center distance D1 between two adjacent physical cells in five equal steps. It will be apparent to those with skill in the art that smaller increments as well as nonlinear progression may be implemented with little difficulty. At the beginning. before

movement. an image is captured. and a new image is recorded at each incremental movement step.

It will be apparent that the fifth move is unnecessary and redundant in this case as the image captured after the fifth move, if taken. would only be essentially the image captured before a move is made. with the cell information shifted by D1. That image is therefore not taken in this example. and the original and the four intermediate images are taken and combined into a composite image of substantially higher resolution than any of the individual images.

The incremental resolution described with the aid of Fig. 3 may, of course, be practiced in the direction at right angles to that shown, providing for a combined image with greatly enhanced resolution in two dimensions.

A significant advantage over the prior art is that. by achieving incremental movements in two-dimensions as described for embodiments of the invention, one may relax the physical dimension requirements for the CCD array. using a much less expensive array than in the prior art. and still achieve greatly enhanced resolution over that of the prior art.

Fig. 4 depicts a sequence of cell displacements according to an alternative embodiment of the present invention that illustrates how micro-motion mechanisms may be used to cause photosensitive semiconductor cells of one color to exchange position with photosensitive semiconductor cells of another color.

Without the benefit of a micro-motion mechanism and positional resolution enhancement according to embodiments of the present invention. the apparent resolution of a color dot, known as a pixel in the art, equals an area bounded by circle 61. Step 1 shows initial positions of a red-sensitive cell 57, a blue-sensitive cell 53, and a green-sensitive cell 55. In step 2, red-sensitive cell 57 is displaced by action of a micro-motion mechanism. as indicated by vector 63. from initial position to the position blue-sensitive cell 53 formerly occupied. In step 3. red-sensitive cell 57 is displaced. as indicated by vector 65, to the position that green-sensitive cell 55 occupied in step 1.

In a similar manner. blue-sensitive cell 53 may exchange positions with cell 55 and cell 57 while green-sensitive cell 55 may

exchange positions with cell 53 and cell 57. As a result of all possible position exchanges, the apparent pixel area of a color-sensitive CCD equipped with a micro-motion mechanism may equal the area of a single color-sensitive cell, rather than the area encompassed by three cells. The resolution for such a system is far superior to the resolution achieved without a micro-motion mechanism.

It will be apparent to those with skill in the art that the cell-exchange technique as described above is not limited to three (RGB) color-photosensitive semiconductor cells, but may be applied to any set of multi-color photosensitive semiconductor cells. Also, it is well known to the inventors that suitable software is needed to assemble multi-scanned images into a single high-resolution image. The necessary control mechanisms for recording the images as positional adjustment is made, and for combining the recorded information into a composite image is well within ordinary skill in the art.

Fig. 5A is a plan view of a CCD array 75 having a bimetal micro-motion mechanism 73 according an embodiment of the present invention for shifting the position of the CCD array as described above. It will be apparent to those with skill in the art that a bimetal micro-motion mechanism may be made an integral part of a CCD array, or an integral part of a frame apparatus, and that in either case the function and implementation of the micro-motion mechanism remains substantially the same.

Micro-motion mechanism 73 comprises silicon substrate (CCD array) 75 having imbedded photosensitive semiconductor cells (not shown), a silicon frame 85 that bounds array 75, a cantilever structure 73 that is produced by etching substrate 75, an electrically conductive region 77 which may be made by doping silicon as is known in the art, a metallic layer 79 consisting of a metal like chromium or aluminum, and an insulator layer 81 that provides an electrical barrier between metallic layer 79 and electrically conductive region 77. Those with skill in the art will recognize that the technology of etching a cantilever in semiconductor material is known in the art. Adding the layers as indicated may be done by other techniques known to those having skill in manufacture of integrated circuits.

Fig. 5B is an elevation view of bimetal micro-motion mechanism

71 of Fig. 5A. Silicon substrate 75, cantilever 73, metallic layer 79, and insulator 81 are shown. Region 77 of cantilever 73 may be made conductive by doping the surface with an impurity such as aluminum or arsenium. Insulator 81 may be made of silicon oxide deposited and patterned in processes developed for IC manufacture.

Conductive area 77 and metallic layer 79 make contact at the tip of cantilever 73. When an electric power source 87 is connected to conductive area 77 and metallic layer 79, it will cause a small current to flow, and as a result, the temperature of cantilever 73 will rise as a result of considerable resistance to current flow.

Because of different temperature expansion coefficients for metallic layer 79 and the semiconductor material of cantilever 73, the cantilever deflects as shown in phantom view 89. As a result, cantilever 73 urges against silicon frame 85 and displaces CCD substrate 75 slightly. The degree of deflection of cantilever 73 is proportional to the temperature, and hence, proportional to the strength of the electric current. Consequently, the displacement of a CCD may be accurately controlled by regulating the electric current flowing through conductive area 77 and metallic layer 79. It will be apparent to one with skill in the art that an asymmetric metallic layer may cause cantilever 73 to deflect in a different direction, which phenomenon may be applied to alter the orientation of cantilever 73.

Fig. 6a is a plan view of a bimetal micro-motion mechanism with a CCD-resident current-control circuit according an alternative embodiment of the present invention. A silicon substrate 99 comprises a cantilever structure 107 having an electrically conductive doped region 97, a metallic layer 95 having an extension 109, an insulator layer 93, and an integrated current-control circuit 101. Current-control circuit 101 may be electrically connected to extension 109 and conductive area 97 by a set of conductive paths 103 and 105. The conductive paths in one embodiment are may be traces created in silicon substrate 99. Those with skill in the art will recognize that the technology of integrated current-control circuitry is known, and that this portion of the present invention may be implemented with little difficulty by those with skill in the art, using well-known equipment and techniques.

Fig. 6b is an edge view of bimetal micro-motion mechanism 107.

Bimetal micro-motion mechanism 107 comprises cantilever 107, metallic layer 95, and insulator 93, as shown in Fig. 6A.

Fig. 7 is a plan view of a piezoelectric micro-motion mechanism 113 according another embodiment of the present invention. Micro-motion mechanism 113 comprises a silicon substrate 115, a cantilever 113, a doped semiconductor area 123, a thin layer of piezoelectric material 117 such as, but is not limited to, lead zirconate titanate (PZT), and a metallic layer 119. When an electric-charge source 125 applies an electric field across piezoelectric material 117 by means of metallic layer 119 and doped semiconductor area 123, piezoelectric material 117 expands along one axis and contracts along another axis. This dimensional distortion is applied to displace silicon substrate 115 in a manner described fully above, and hence, displace photosensitive semiconductor cells as illustrated in Fig. 2, Fig. 3 and Fig. 4.

In embodiments of the present invention, only one micro-motion mechanism for the X axis and one micro-motion mechanism for the Y axis may be needed if each of the opposing micro-motion mechanisms are replaced by a piece of resilient material. Since a resilient material acts like a spring, a resilient piece reverses the displacement of a CCD when its opposing micro-motion mechanism fully or partly relaxes.

In still another embodiment of the present invention a magnetostrictive material such as Terfenol-D may be used to construct micro-motion mechanisms. Since magnetostrictive materials change dimensions when exposed to a magnetic field, a small electromagnet may be used to actuate a micro-motion mechanisms made of magnetostrictive material.

Fig. 8 is a plan view a three-color (RGB) camera 131 according an embodiment of the present invention wherein three separate CCD arrays are utilized, and each array may be moved independently by a micro-motion mechanism. The micro-motion mechanisms are not shown, but are implemented in frames with each CCD array as described above. Camera 131 comprises a prism 133, a lens 135, a CCD array 137 that is sensitive to red light, a CCD array 139 that is sensitive to green light, and a CCD array 141 that is sensitive to blue light. Each CCD array is equipped with a set of micro-motion mechanisms that displace its photosensitive semiconductor cells in a manner as previously

described to increase captured-image resolution. The information obtained from captured multi-scanned images of each CCD is then combined and used to assemble a single high-resolution color image.

The present invention also significantly improves resolution of digital video cameras. For example, the mass of a cantilever of a micro-motion mechanism as described above can be made small enough to allow repetitive deflections at a rate that surpasses the line-scan frequency used in conventional digital video cameras. Such a quick-response micro-motion mechanism allows multiple CCD array displacements and associated line scans within a single line-scan period of a conventional digital video camera. Upon completion of each line scan, a camera-resident software program uses information obtained from the multiple line-images to assemble and store a single high-resolution line. The program also ensures that a CCD array returns to its initial position, ready for a next line to be scanned.

Fig. 9 is an isometric view of a video camera 66 according to an embodiment of the present invention. In this camera, as described above, a sensor array is oscillated in the plane of the array by micro-motion mechanisms, and scans of cells an the array to produce images are initiated and guided by control routines executed by a local CPU.

There are particular advantages for a digital video cameras. For example, a judicious selection of the number of cells in each column and line allows for resolution to be adjusted to existing and perhaps future video standards. An 80 x 60 array of cells may be used, for example, to produce frames of 640 x 480 by recording images in seven positions between each physical position. The effect is multiplying the number of columns and lines in a image array by eight. The same 80 x 60 array may be multiplied by ten in each direction to produce an 800 x 600 image. The resolution can be set and reset by software.

Fig. 10 is a flow diagram depicting a general process flow for making a composite scan using a movable cell device according to various embodiments of the present invention. The flow diagram assumes that the apparatus (camera, scanner) using the movable cell device is digitally controlled, and that a pre-programmed sequence determines the number of scans (images) to be taken and the timing and magnitude of movement by micro-motion mechanisms.

The logical flow in Fig. 10 begins with initiation of a scan sequence at step 40. After initiation, a first reading of an array or linear bar is taken at step 42, before movement of the array or bar by a micro-motion mechanism. Then, at step 44, the bar or array is moved a small increment (which may be in any direction, and the direction in subsequent movements may change, according to a pre-programmed sequence). After movement, a subsequent reading is taken at step 46. After a subsequent reading, a decision is made at step 48 as to whether the sequence is complete.

If the sequence is not complete, control goes back to step 44, another movement is made, and then control goes again to step 46, where another subsequent reading is made. If at step 48 the decision is that the procedure is complete, control goes to step 50, where the scan procedure is complete, and processing of the collected data may begin. Variations and adaptions of the general stepwise procedure shown may be necessary for various alternative embodiments of the present invention.

It will be apparent to those with skill in the art that there are many alterations in detail that may be made in embodiments described without departing materially from the spirit and scope of the invention. For example, various embodiments of the invention have been described as using photosensitive arrays, and moving an array in the plane of the array to enhance resolution. The invention is not limited to sensors that sense visible light, however, but may be practiced with arrays of sensors that sense, for example, ultraviolet or infrared radiation, or other sorts of electromagnetic radiation. Applications of such sensing apparatus might include illuminating and recording systems for night vision.

As another example of variations in detail that fall within the spirit and scope of the invention, several micro-motion mechanisms have been described, but others are feasible and would fall within the scope of the invention as equivalent mechanisms. There are similarly many variants in size for CCD arrays, and multiple resolutions may be obtained by changing the incremental movement of arrays.

As yet another example of the breadth of the invention, there are many variants that might be made in positioning cell arrays for various purposes. For example, after an initial scan, subsequent scans made

after movement of the physical cell array may be done selectively. with fewer than all of the cells being scanned, for example, every second cell. This approach allows quicker scanning of cell arrays without significant sacrifice of resolution. Also. non-linear scans of various sorts can be utilized in conjunction with coded instructions to accomplish digital filtering and enhancements in sensed images.

What is claimed is:

1. A system for capturing images, comprising:

an array of sensor cells including connection circuitry for coupling the cells to outside circuitry; and

a micro-motion mechanism in contact with the array of sensor cells, including connections for power and control input to the micro-motion mechanism;

wherein the micro-motion mechanism is adapted for moving the cell array in at least one direction in the plane of the cell array.

2. A system as in claim 1 wherein the cell array comprises an array of charge-coupled devices (CCDs) implemented on a semiconductor substrate.

3. A system as in claim 1 wherein the micro-motion mechanism comprises a bi-metallic cantilever device implemented on an edge of the cell array.

4. A system as in claim 1 wherein the micro-motion mechanism comprises a piezoelectric device.

5. A system as in claim 1 comprising multiple micro-motion mechanisms adapted for moving the cell array in two directions at right angles and both in the plane of the array.

6. A sensor cell bar for capturing images. comprising:

a linear array of sensor cells arranged along a linear axis including connection circuitry for coupling the cells to outside circuitry; and

a micro-motion mechanism in contact with the linear array of sensor cells. including connections for power and control input to the micro-motion mechanism:

wherein the micro-motion mechanism is adapted for moving the cell array in the direction of the linear axis of the linear array.

7. A sensor cell bar as in claim 1 wherein the cell bar comprises a linear array of charge-coupled devices (CCDs) implemented on a semiconductor substrate.

8. A sensor cell bar as in claim 1 wherein the micro-motion mechanism comprises a bi-metallic cantilever device implemented on an edge of the cell bar.

9. A sensor cell bar as in claim 1 wherein the micro-motion mechanism comprises a piezoelectric device.

10. A sensor cell system for capturing images. comprising:

an array of sensor cells including connection circuitry for coupling the cells to outside circuitry;

a digital memory;

sensing and control circuitry coupled to the cells and to the digital memory and adapted for measuring output of individual cells and for storing bit-mapped images relative to the output of individual cells; and

a micro-motion mechanism in contact with the array of photosensitive cells;

wherein the control circuitry controls the micro-motion mechanism to move the cell array in discrete increments in the plane of the array of cells. and controls the individual cells to sense output of the cells between moves of the micro-motion mechanisms. storing bit-mapped images in the digital memory relative to the outputs of the cells.

11. A sensor cell system as in claim 10 wherein the cell array comprises an array of charge-coupled devices (CCDs) implemented on a semiconductor substrate.

12. A sensor cell system as in claim 1 wherein the micro-motion mechanism comprises a bi-metallic cantilever device implemented on an edge of the cell array.

13. A sensor cell system as in claim 10 wherein the micro-motion mechanism comprises a piezoelectric device.

14. A sensor cell system as in claim 10 comprising multiple micro-motion mechanisms adapted for moving the cell array in two directions at right angles and both in the plane of the array.

15. A digital still camera comprising:

an outer case;

an array of sensor cells within the case;

a lens system adapted for focusing an image from outside the case on the cell array;

a digital memory;

sensing and control circuitry coupled to the cells and to the digital memory and adapted for measuring output of individual cells and for storing bit-mapped images in the digital memory relative to the output of individual cells; and

a micro-motion mechanism in contact with the array of photosensitive cells;

wherein the control circuitry controls the micro-motion mechanism to move the cell array in discrete increments in the plane of the two-dimensional array of cells. and controls the individual cells to sense output of the cells between moves of the micro-motion mechanisms. storing bit-mapped images in the digital memory relative to the outputs of the cells.

16. A digital video camera comprising:

an outer case;

an array of sensor cells within the case;

a lens system adapted for focusing an image from outside the case on the cell array;

a digital memory;

sensing and control circuitry coupled to the cells and to the digital memory and adapted for measuring output of individual cells and for storing bit-mapped images in the digital memory relative to the output of individual cells: and

a micro-motion mechanism in contact with the array of photosensitive cells;

wherein the control circuitry controls the micro-motion mechanism to move the cell array in discrete increments in the plane of the two-dimensional array of cells, and controls the individual cells to sense output of the cells between moves of the micro-motion mechanisms, storing bit-mapped images as video frames in the digital memory relative to the outputs of the cells.

17. A flat bed scanner comprising:

an enclosure having a support glass for supporting a document to be scanned;

a cover attached to the enclosure and adapted to close over the support glass;

an array of sensor cells within the case;

An illumination source for illuminating the document to be scanned;

a digital memory;

sensing and control circuitry coupled to the cells and to the digital memory and adapted for measuring output of individual cells and for storing bit-mapped images in the digital memory relative to the output of individual cells: and

a micro-motion mechanism in contact with the array of photosensitive cells;

wherein the control circuitry controls the micro-motion mechanism to move the cell array in discrete increments in the plane of the array of cells, and controls the individual cells to sense output of the cells between moves of the micro-motion mechanisms, storing bit-mapped images in the digital memory relative to the outputs of the cells.

18. A document-feeding scanner comprising:

a scanner bar having a linear arrangement of photosensitive cells along a linear axis;

a document feeder adapted for moving a document to be scanned past the scanner bar;

a digital memory;

sensing and control circuitry coupled to the photosensitive cells and to the digital memory and adapted for measuring output of individual cells and for storing bit-mapped images in the digital memory relative to the output of individual cells; and

a micro-motion mechanism in contact with the scanner bar;

wherein the control circuitry controls the micro-motion mechanism to move the scanner bar in discrete increments in the direction of the linear axis of the scanner bar. and controls the individual cells to sense output of the cells between moves of the micro-motion mechanism, storing bit-mapped images in the digital memory relative to the outputs of the cells.

19. A hand-held scanner comprising:

a scanner bar having a linear arrangement of photosensitive cells along a linear axis;

a window whereby the scanner bar is exposed to a document to be scanned as the scanner bar is translated over the document;

a digital memory;

sensing and control circuitry coupled to the photosensitive cells and to the digital memory and adapted for measuring output of individual cells and for storing bit-mapped images in the digital memory relative to the output of individual cells; and

a micro-motion mechanism in contact with the scanner bar;

wherein the control circuitry controls the micro-motion mechanism to move the scanner bar in discrete increments in the direction of the linear axis of the scanner bar, and controls the individual cells to sense output of the cells between moves of the micro-motion mechanism. storing bit-mapped images in the digital memory relative to the outputs of the cells.

20. A method for enhancing resolution for sensed images. comprising steps of:

(a) focusing an image on a sensor array;

(b) measuring first output from individual sensor cells in the sensor array;

(c) storing the relative output of the sensor cells as a first bit-

mapped image in a digital memory;

(d) moving the sensor array;

(e) measuring second output from the individual sensor cells;

(f) storing the relative output of the sensor cells as a second bit-mapped image in the digital memory; and

(g) combining the first and the second bit-mapped images into a composite bit-mapped image.

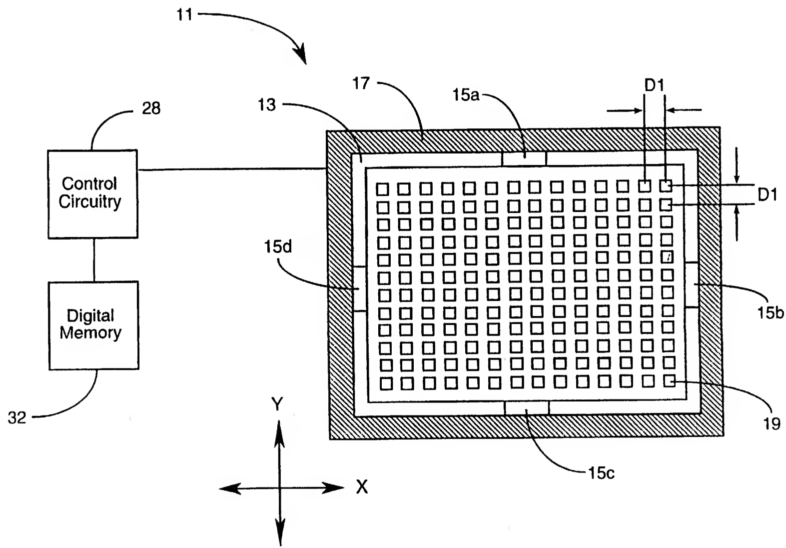
11
Control
Circuitry
28
Digital
Memory
32
13
17
15a
D1
D1
15d
15b
19
15c
Y
X

Fig. 1A

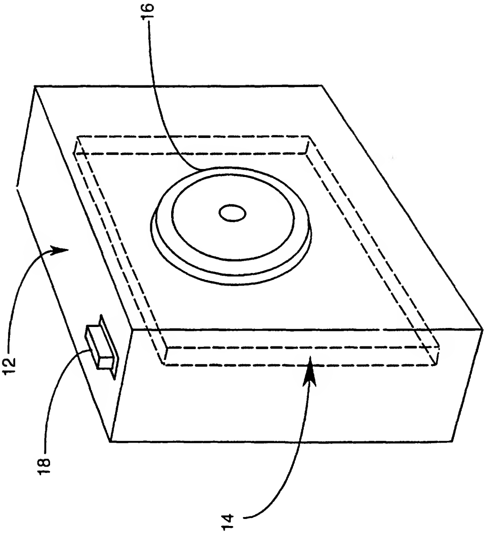

Fig. 1B

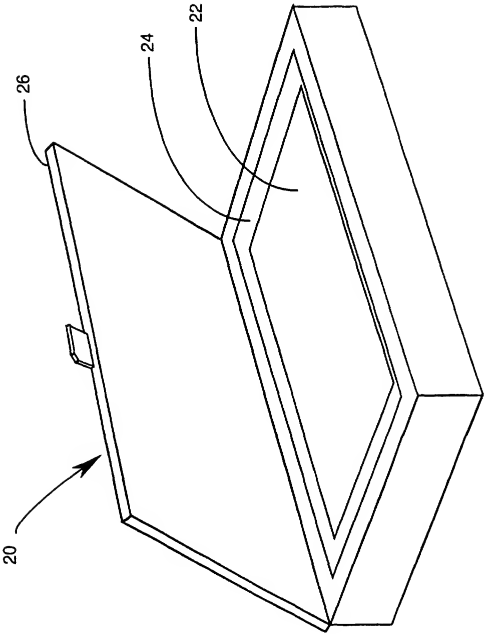

Fig. 1C

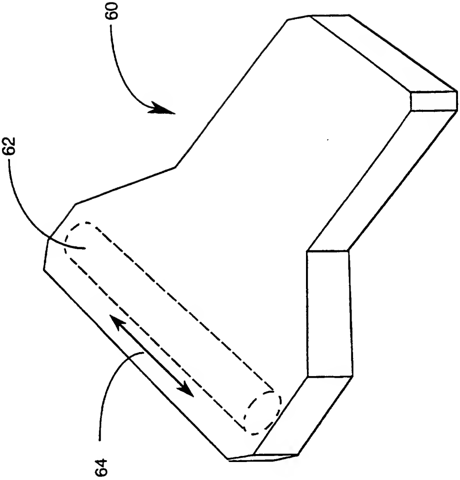

Fig. 1D

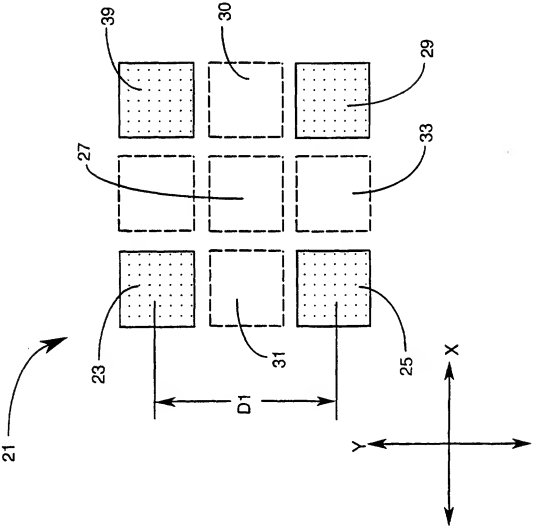

Fig. 2

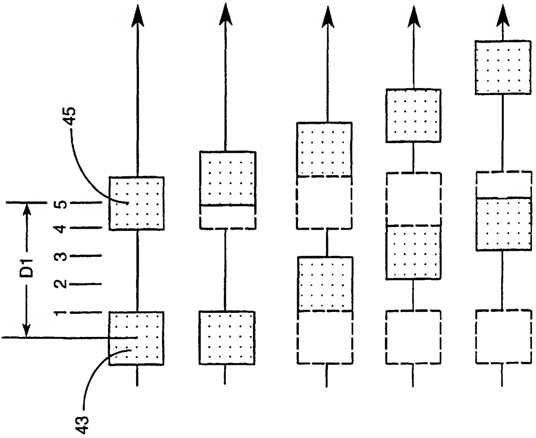

Fig. 3

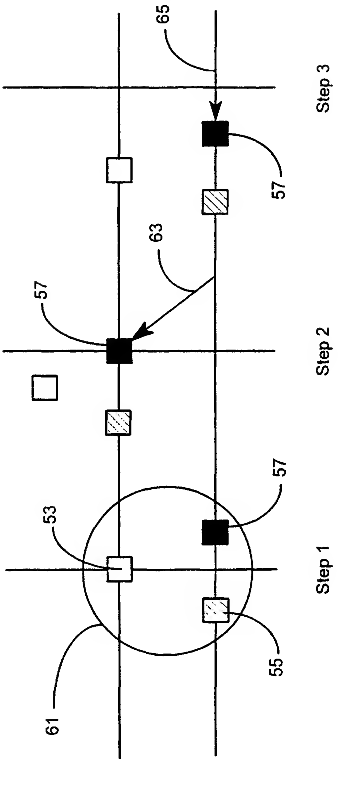

Fig. 4

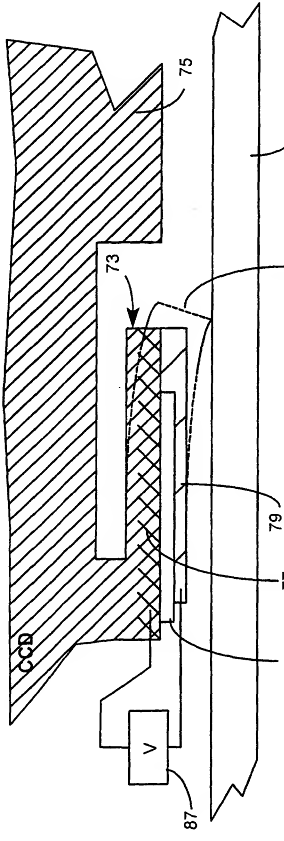

Fig. 5A

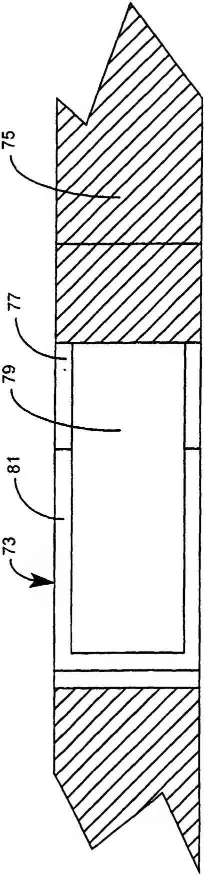

Fig. 5B

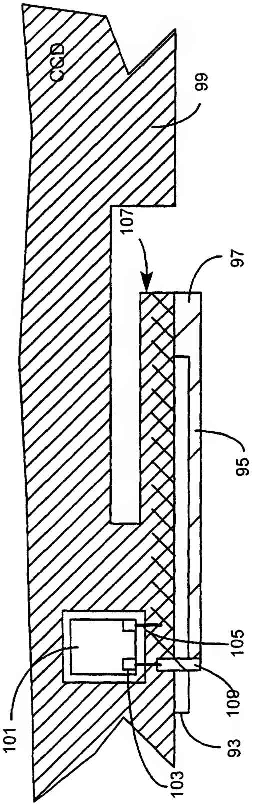

Fig. 6A

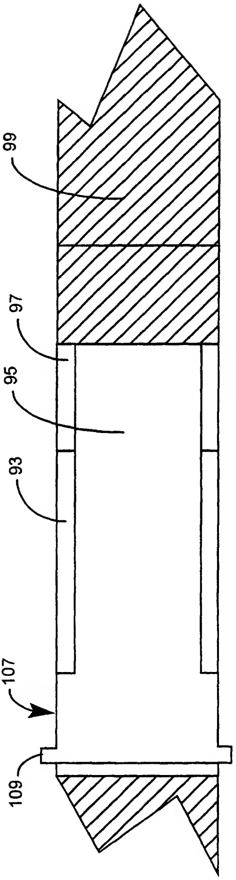

Fig. 6B

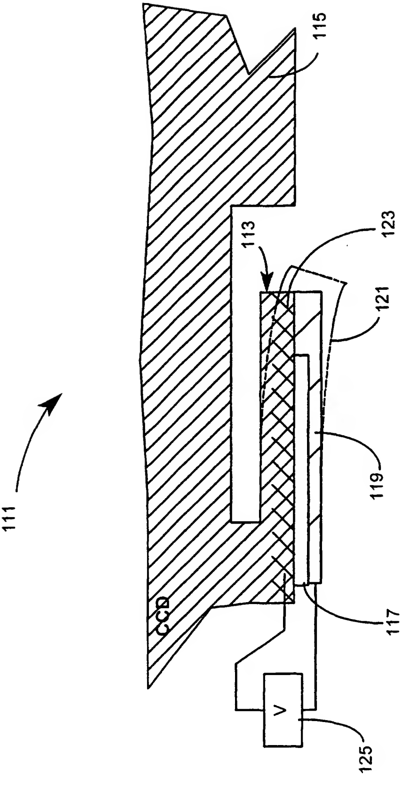

Fig. 7

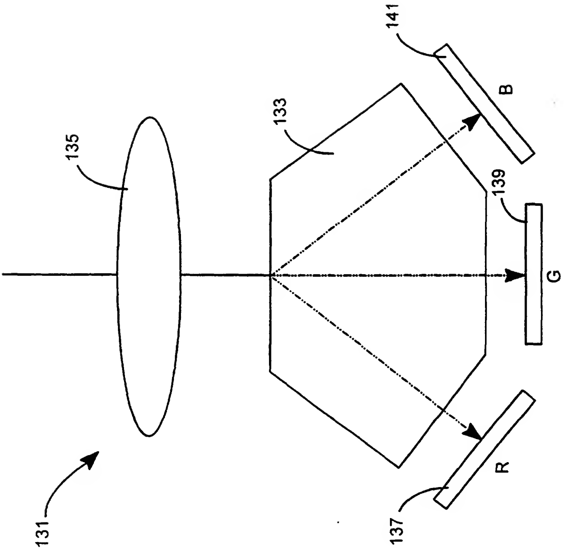

Fig. 8

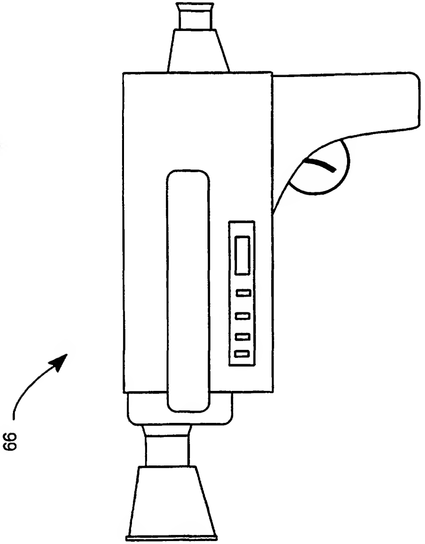

Fig. 9

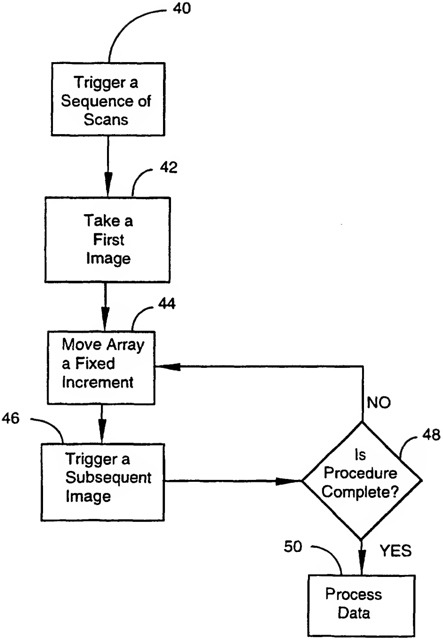
40
Trigger a Sequence of Scans
42
Take a First Image
44
Move Array a Fixed Increment
46
Trigger a Subsequent Image
NO
48
Is Procedure Complete?
50
YES
Process Data

Fig. 10

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US96/15547

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :H04N 5/225
US CL :348/207, 218, 219, 294, 311 and 375
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 348/207, 218, 219, 294, 311 and 375

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

None

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 5,063,450 A (PRITCHARD) 05 November 1991, col. 2, lines 63-68 and col. 3.	1, 2, 4-7, 9-11,13-16, 1, 2, 4-7, 9 --------------- 3, 8,10-16, 20
X -- Y	US 4,607,287 A (ENDO et al) 19 August 1986, col.3, lines 26-68, cols. 4 and 5.	1-2, 4-7, 9, ---- ---------- 10-11, 13, 14-16, 20
X --- Y	US 4,595,954 A (ENDO et al) 17 June 1986, cols. 3 and 4.	1,2, 5-7 ----------- 3, 4, 8, 9

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be part of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search
15 JANUARY 1997

Date of mailing of the international search report
13 FEB 1997

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US96/15547

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 4,998,164 A (ENDO et al) 05 March 1991, cols. 3, 4 and 5.	1, 2, 4-7 --- 3, 8,10-16, 20

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US96/15547

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1-16 and 20

Remark on Protest ☐ The additional search fees were accompanied by the applicant's protest.
☐ No protest accompanied the payment of additional search fees.